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The role of cognitive skills in economic development revisited

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経済発展における認知スキルの役割 —Hanushek and Woessmann の再検討—

コーワタナサクン　ウッパラット*

Abstract

As one of the driving forces of economic growth that has been incorporated into cross-country growth regression analyses, human capital continues to lack a precise definition and measurement, and is proxied by variables such as adult literacy rates, school enrolment ratios, years of school attainment and student achievement scores in empirical studies. In a recent work, Hanushek and Woessmann (2008) posited that international student achievement scores would also be a suitable proxy for the estimation of the causal relationship between cognitive skills, human capital, and economic growth, adding that their results are not sensitive to different robustness checks. This paper examines the robustness of Hanushek and Woessmann's regression results and examines the stability of causal relationships over time, as well as the extent of dependence of their results on sample-country composition. A sensitivity analysis on two levels—time period and sample size—was conducted, and results showed that the convergence rate remained strongly statistically significant across all sensitivity analyses, but test scores became statistically insignificant in some sensitivity analyses. This paper thus argues that Hanushek and Woessmann's result is reasonably robust to most sensitivity analyses; however, changing the composition of sample size and data set may affect the results. A brief discussion, country analysis, and future directions for further research regarding the implications of the results are also provided.

Keywords: Growth regression, Sensitivity analysis, Test score, Human capital

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1. Introduction

Human capital[1] plays a crucial role in explaining economic growth. Theoretically, human capital leads to economic growth both directly and indirectly through mechanisms like technological progress, and improvement in the total production function. As one of the driving forces of economic growth that has been incorporated into cross-country growth regression analyses, human capital continues to lack a precise definition and measurement, and is proxied by variables such as adult literacy rates, school enrolment ratios, years of school attainment, and student achievement scores in empirical studies. Hanushek and Woessmann (2008) recently posited that international student achievement scores would also be a suitable proxy for the estimation of the causal relationship between cognitive skills, human capital, and economic growth, adding that their results are not sensitive to different robustness checks. However, in their analysis, sample countries composed of advanced economies with shared characteristics that were willing to participate in international student assessment tests. This might have led to a self-selection bias, and thus an overestimation of the effect of cognitive skills on economic growth.

This paper examines the robustness of Hanushek and Woessmann's regression results and examines the stability of causal relationships over time, as well as the extent of dependence of their results on sample-country composition. In other words, this paper conducts a sensitivity analysis on two levels—time period and sample size. The robustness testing is limited to Hanushek and Woessmann's sample size of fifty countries over different time periods to observe patterns and changes in the statistical quantity and quality of independent variables. Then, a larger sample size is pooled to test whether their results depend on a certain set of sample countries, and to examine patterns and changes in the statistical properties of independent variables over different sample sizes.

The originality of this research lies in the author's use of updated economic and education data. International student achievement tests that were previously unavailable and the most recent data on school attainment and economic growth over a longer time period (1960-2010) were taken into consideration. As such, this paper covers a modern economic era with an evolving significance of human capital on economic growth. Sample countries were also increased from fifty in Hanushek and

1 The term human capital is rather vague and ambiguous. According to Schultz (1992), human capital refers to "education, talent, energy, and will". Adding onto to Schultz (1992), Becker (1993) proposed a more specific definition to refer to "expenditures on education, training, medical care, ... [that] produce human, not physical or financial, capital because you cannot separate a person from his or her knowledge, skills, health, or values the way it is possible to move financial and physical assets while the owner stays put." Insofar, the most comprehensive and concrete definition was provided by Husz (1998) who puts that, "[b]y human capital we mean the time, experience, knowledge and abilities of an individual household or a generation, which can be used in the production process".

Woessmann (2008) to eighty countries[2]. With the larger number of sample countries and the corresponding increase in variations between sample country characteristics, statistical quality and quantity might be affected. An increase in sample size might also further help to reduce self-selection bias.

This paper consists of five sections. The next section provides a brief literature review and focuses on the recent study by Hanushek and Woessmann (2008). The third section deals with data description and the theoretical framework of a cross-country regression analysis. Results of different sensitivity analyses are provided in section four. Finally, the last section provides a brief conclusion and discussion, and future directions for further research.

2. Cognitive skills[3] and economic growth

Various indicators have been used by earlier studies as proxies of human capital, including adult literacy rates (e.g., Azariadis and Drazen, 1990; Romer, 1990), school enrolment ratios (e.g., Barro, 1991; Mankiw, Romer and Weil, 1992; Levine and Renelt, 1992), years of school attainment (e.g., Lau, Jamison, and Louat, 1991; Banhabib and Spiegel, 1994), and student achievement scores[4]. Woessmann (2003) made a complete review of human capital proxies traditionally used in economic growth regressions. He contended that human capital is poorly proxied when researchers adopt adult literacy rates, school enrollment ratios, or even average years of schooling in regression models. Using these proxies, researchers implicitly assume that every country possesses the same quality of education (Hanushek and Woessmann, 2008), thus neglecting the qualitative dimension of education. As cognitive skills are related, among other proxies, to both the quantity and quality of schooling, Hanushek and Woessmann (2008) adopted cognitive skills as a proxy of human capital, in which they can be quantified by test scores. Hanushek and Woessmann (2008) went on to enlarge the existing database in both test scores and economic growth to a longer time period (1960-2000) with more sample countries (fifty countries), and affirmed previous findings of Jamison, Jamison and Hanushek (2006) and Coulombe and Tremblay (2006), that human capital proxied by student achievement scores indeed has a positive and statistically significant relationship with economic growth. Their test scores data set was compiled from various sources of international student assessment at different points in time to pool

[2] The sample size in regression analysis depends on availability of test score, years of schooling and growth information. Moreover, it also depends on the level of analysis.

[3] According to the McGraw-Hill Concise Dictionary of Modern Medicine (2002), it defines cognitive skills as "any of a number of acquired skills that reflect an individual's ability to think; cognitive skills include verbal and spatial abilities, and have a significant hereditary component".

[4] See Woessmann (2003) and Hanushek and Woessmann (2011) for a complete and comprehensive list of human capital proxies.

sample sizes as large as possible. In their proposed regression model, only years of schooling and test scores were treated as independent variables. They concluded that the effect of test scores in explaining growth was much higher than that of years of schooling. Even after trade openness, protection against expropriation, and regional dummies were introduced into the model, test scores were still significantly related to economic growth, while years of schooling remain insignificant. Furthermore, by changing the time period and components of test scores and subsample, different regressions were run in order to check the robustness of the original regression results. Statistical quality of test scores and years of schooling remained the same, implying a strong robustness of the results. Nevertheless, as the magnitude of coefficients of the regression results from different robustness checks were not specified in the article. Thus, it is ambiguous as to whether the effect of human capital on economic performance was consistent among different robustness checks.

3. Conceptual framework, methodology, and data

3.1 Conceptual framework and methodology

This section is a brief discussion of the mathematically conceptual framework underlying Hanushek and Woessmann's model (henceforth Hanushek and Woessmann). Based on the Mincerian wage equation, Hanushek and Woessmann tried to examine whether test scores have an impact on GDP growth by using a microeconomic framework with aggregate data to analyze the relationship between human capital and growth at macro level.

$$y = \gamma H + \varepsilon . \tag{1}$$

First, Hanushek and Woessmann presented a simple earnings model in which individual earnings (y) are a function of individual skills referred to as human capital (H). The stochastic term, ε, represents exogenous factors affecting individual earnings and this term does not statistically relate to H. On a macro level, this equation is translated into

$$g = \gamma H + \beta X + \varepsilon . \tag{2}$$

g is a country's growth rate. On the right hand side, H now represents a function of the skills of workers, while X represents other factors that affect the country's growth rate. The function of individual skills is specified then. These skills can develop in many different ways and are affected by many factors. However, previous studies (e.g. Ben-Porath, 1967 & 1970; Heckman, 1976; Cunha et al., 2006) specified a set of independent variables in the function, including family inputs (F), school factors ($Q(S)$), both in terms of quantity and quality, individual ability (A), and other relevant factors (X). Note that S in the equation represents years of schooling. The quality of education is incorporated in the equation since there is evidence that the quality of schooling varies across schools, cities, and even countries.

$$Q(S) = qS. \tag{3}$$

$$H = \lambda F + \beta Q(S) + \delta A + \alpha X + \upsilon. \tag{4}$$

In this article, the following model is used in the main analysis.

$$g = \beta_0 + \beta_1 \textit{ initial GDP per capita} + \beta_2 \textit{ years of schooling} + \beta_3 \textit{ test scores} + \varepsilon. \tag{5}$$

This proposed model is the simplest form of the extended version in the neoclassical model that is widely used in cross-country growth regression analysis (Barro, 1997, and Barro and Sala-i-Martin, 1995). As this research mainly focuses on the effect of human capital (with test scores as a proxy) on economic growth (g), only initial GDP per capita, years of schooling and test scores are specified in the model. This paper adopts this model so as to replicate Hanushek and Woessmann's regression results and to check the sensitivity of their model with recent data sets on test scores and with extended sample size. The growth regression analysis was performed using multiple regression analysis with cross-sectional data. The model coefficients and statistics were estimated using an ordinary least squares (OLS) estimate. Throughout the multiple regression analysis, a coefficient is considered statistically significant if the p-value is below 0.10. The unit of analysis was taken at the national level.

3.2 Operational definitions

On one hand, *average annual growth rate in GDP per capita* is the dependent variable and is measured by an average annual growth rate in GDP per capita (PPP) over a specific time period. On the other hand, there are three explanatory variables specified in this model. Firstly, *GDP per capita*, depending on a period of analysis, refers to an initial level of GDP per capita for each country. Secondly, *years of schooling* refers to years of schooling of population aged 25 and over in an initial year of an analysis. The other explanatory variable of interest is *test score*. It refers to a simple average of the mathematics and science scores over a specific time period.

3.3 Data

The data used in this paper mainly follows the same source and methods of estimation as Hanushek and Woessmann's, to closely replicate their regression results. As a measure of cognitive skills, test scores is a simple average of the mathematics and science scores over a specific time period. In replicating Hanushek and Woessmann's

Table 1 Summary statistics for base and additional samples

Variable	Analyses	Year/Period	Observations	Mean	Std.Dev.	Min	Max
Growth in GDP per capita	- Table 1-4	1960-2000	46	2.863	1.441	.348	6.495
	- Table 5	1960-2010	46	6.874	3.150	2.468	15.303
	- Table 6	1960-2010	53	6.854	3.240	2.135	15.303
		1970-2010	62	2.450	1.334	.162	5.783
	- Table 7	1980-2010	62	2.089	1.314	-.834	6.022
		1990-2010	73	2.201	1.249	-1.058	5.62
		2000-2010	73	2.474	1.957	-.584	9.314
Initial GDP per capita ('000)	- Table 1-4	1960	46	6.655	5.103	.665	21.005
	- Table 5	1960	53	6.484	5.174	.665	21.005
	- Table 6	1970	62	9.203	7.125	.816	29.442
		1980	62	12.431	8.743	1.145	31.954
	- Table 7	1990	73	15.913	12.130	1.273	64.255
		2000	73	19.601	14.975	1.478	65.126
Years of schooling	- Table 1-4	1960	47	4.529	2.555	.329	9.76
	- Table 5	1960	53	4.397	2.544	.329	9.76
	- Table 6	1970	62	5.086	2.597	.268	10.756
		1980	62	6.176	2.676	1.241	11.936
	- Table 7	1990	73	7.459	2.377	2.203	12.34
		2000	73	8.628	2.179	3.366	13.003
Test score	- Table 1-4	1990-2000	46	4.551	.866	1.873	5.863
		1990-2010	47	4.578	.795	2.017	5.846
		2000-2010	47	4.592	.843	1.717	5.964
		1960-2000a	43	4.505	.625	3.089	5.338
	- Table 5	1990-2000	47	4.539	.874	1.873	5.863
		1990-2010	53	4.513	.786	2.017	5.846
		2000-2010	53	4.527	.829	1.717	5.964
	- Table 6	1990-2000	55	4.524	.831	1.873	5.863
		1990-2010	62	4.516	.748	2.017	5.846
		2000-2010	62	4.542	.791	1.717	5.964
	- Table 7	1990-2000	73	4.553	.822	1.873	5.863
		1990-2010	73	4.523	.735	2.017	5.846
		2000-2010	73	4.546	.772	1.717	5.964

Note: a Test score data from Hanushek and Woessmann (2008)
Source: Author's compilation

results (1960-2000), the standardized international test scores calculated and provided in their article are used. According to their method of calculation[5], the author standardizes the measurement of cognitive skills in the 1990-2010 period. However, when the period of analysis was extended to 2010, the calculation of the mean of test scores

[5] See Hanushek and Woessmann (forthcoming) for more details.

only covers the 1990-2010 period, which is different from that of Hanushek and Woessmann whose data period for cognitive skills is from 1960 to 2000. Only the Trends in International Mathematics and Science Study (TIMSS) and the Programme for International Student Assessment (PISA) are included in the calculation. TIMSS internationally measures trends in mathematics and science achievement at the fourth and eighth grades on a regular 4-year cycle since 1995, while PISA evaluates trends in mathematics, science, and reading achievement of 15-year-old students on a regular 3-year cycle since 2000. TIMSS and PISA are the largest and most accepted and reliable database on international test scores. The First International Mathematics Study (FIMS), the First International Science Study (FISS), Second International Mathematics Study (SIMS), and Second International Science Study (SISS) are excluded from the calculation of average test scores due to data unavailability. These data are not available either from their official website nor Hanushek and Woessmann's articles and websites. Hence, to estimate the causal relationship between cognitive skills and economic growth for 1960-2010, an assumption that test scores are reasonably constant over time (Hanushek and Woessmann, 2008) was required. According to Hanushek and Woesmann's definition, the measure of cognitive skills is interpreted as a proxy for the average educational performance of the whole labor force.

The Penn World Table 6.1 (PWT 6.1, as used by Hanushek and Woessmann) and the Penn World Table 7.1 (PWT 7.1, Heston, Summers, and Aten, 2012) are the sources for the initial GDP per capita data and the calculation of average annual growth rate in GDP per capita for a specific time period. The Penn World Table (PWT) provides a set of national accounts economic time series covering countries worldwide. It is widely used by economists as PWT is constructed through a set of sophisticated extrapolations and techniques from the benchmark studies, both through time and across space; therefore, PWT is the most advanced international database that may be referred to as a Space-Time System of National Accounts. This paper opts to use PWT 7.1 as it covers a more recent year (2010) and more countries (189 countries) than that of PWT 6.1 (2000 and 168 countries). Aside from the more updated and wider country coverage, another main difference between PWT 6.1 and PWT 7.1 is that the former adopts 1996 as a reference year, while the latter uses 2005 as a reference year. This might affect a comparison of a magnitude of coefficients from different regressions using different PWT data. However, statistical properties should remain unchanged and should be comparable between results from two different data sets. To reduce the incomparable issues that might occur, the author mainly uses PWT 7.1 in the analysis, from Table 3 to Table 14. In Table 3, the author compares the differences of the regression results from the models using the data from PWT 6.1 and PWT 7.1.

This paper adopts the Cohen and Sato data set (2007) and the Barro and Lee data set (2011) for data on years of schooling. Years of schooling or educational attainment features the average years of schooling for the adult population over age 25. The methods of estimation are different between these two data sets; however, their data sets are strongly and positively correlated. This paper mainly uses the Barro and Lee data set as it is more updated (Table 3 to Table 14.)

Data from different sources are used for different purposes. On one hand, PWT 6.1 and the Cohen and Sato data set is used mainly to replicate Hanushek and Woessmann's main result, while PWT 7.1 and the Barro and Lee data set are used for the sensitivity analysis with extended time period and sample size.

3.4 Data limitations

Even though a more updated data and wider sample size can be obtained, the data for each country either on GDP per capita, test score, or years of schooling start from different points in time. As a result, the regression analyses are divided into four main sample sizes, including 47 countries, 53 countries, 62 countries and 73 countries. In the analyses carried out in this study, the author tries to equate a number of sample sizes for meaningful interpretation. However, as the sample size expands to include recent years and compares results of different sample sizes, a compromise is made between accuracy of the comparison and better regression estimation with a lesser tendency of self-selection bias. Table 2 explains differences between these samples.

4. Estimation results: the impacts on economic growth

4.1 Basic results

The replicated results without test score variables are presented in Table 3. Compared to Hanushek and Woessmann's result (column 1), the result (column 2) is consistent; both the evidence of convergence and school attainment are statistically significant. However, after adopting a new data set for GDP per capita, the association between years of schooling and growth turns insignificant (column 3 and 4). There is a tendency that Hanushek and Woesmann's regression result is sensitive to the choice of data and the change in period of analysis. Table 4 indicates the replicated results after introducing test scores into the model. Both qualitative and quantitative sizes are consistent with Hanushek and Woessmann's original results (column 1). Using test scores in period 1990-2000 to estimate the causal relationship between cognitive skills and economic growth for a wider period of 1960-2000 generates a similar result to that of Hanushek and Woessmann (column 3). In other words, even though Hanushek and Woessmann's test scores data covers a wider range of data points (1960-2000), the test scores with a shorter range of data points (1990-2000) have similar explanation power.

The adjusted R^2 is reasonably high in all columns in which around 70 percent of the variation in economic growth can be explained by the model. Hence, there is reason to believe that using test scores from year 1990-2000 would not significantly alter the statistical quality of the regression model; however, the magnitude of the coefficient might be underestimated or overestimated.

The GDP per capita from PWT 7.1 is used in the analysis to examine whether the regression result is robust to change in the data set after introducing test scores in the model. The results in Table 5 is similar that of Hanushek and Woessmann (column 1). The adjusted R^2 is considerably high in all columns. Nonetheless, extending the period of analysis by ten years (column 5) reduces the magnitude of the coefficient for both convergence rate and test scores by half. This suggests that altering the time period

Table 2 Differences among sample sizes

Sample size	Initial year of data availability	Country list
47 countries	1960	Hanushek and Woessmann's sample (50 countries) including Argentina Australia, Austria, Belgium, Brazil, Canada, Chile, China, Chinese Taipei, Colombia, Cyprus, Denmark, Egypt, Finland, France, Ghana, Greece, Hong Kong, Iceland, India, Indonesia, Iran, Ireland, Israel, Italy, Japan, Jordan, Korea, Malaysia, Mexico, Morocco, Netherlands, New Zealand, Norway, Peru, Philippines, Portugal, Romania, Singapore, South Africa, Spain, Sweden, Switzerland, Thailand, Tunisia, Turkey, United Kingdom, United States, Uruguay, and Zimbabwe. *Test scores data are not available for China, India, and Zimbabwe.
53 countries	1960	47-countries sample plus Algeria, Botswana, El Salvador, Luxembourg, Panama, Syrian Arab Republic, and Trinidad and Tobago. *Tunisia is excluded from the sample since GDP per capita data is not available.
62 countries	1970	53-countries sample plus Albania, Bahrain, Bulgaria, Germany, Hungary, Macao-China, Malta, Poland, and Tunisia.
62 countries	1980	Same as 1970
73 countries	1990	62-countries sample plus Croatia, Czech Republic, Dubai (UAE), Estonia, Kuwait, Qatar, Russia, Saudi Arabia, Serbia, Slovak Republic, and Slovenia.
73 countries	2000	Same as 1990

Note: Some variations in sample size that are not indicated here are explained under each table.
Source: Author's compilation

Table 3 Replication of Hanushek and Woessmann's regression results without test scores

Dependent variable: average annual growth rate in GDP per capita				
	HW[a] 1960-2000	1960-2000	1960-2000 (PWT7.1)	1960-2010 (PWT7.1)
GDP per capita	-0.379 ***	-0.296 ***	-0.340 **	-0.161**
		(0.085)	(0.161)	(0.069)
Years of schooling	0.369 ***	0.324 ***	0.503	0.181
		(0.114)	(0.301)	(0.128)
Constant	2.785	2.582	5.065	2.675
		(0.312)	(0.853)	(0.363)
N	50	43[b]	43	43
R^2 (adj.)	0.252	0.2003	0.058	0.1119

Note: Standard errors in parentheses Source: Author's compilation

a Results from Hanushek and Woessmann (2008)

b Cyprus, Hong Kong, Iceland, Israel, Singapore, Taiwan, and Tunisia are not included in the sample. Although the author uses data from the same source as Hanushek and Woessmann did, These countries included in Hanushek and Woessmann's sample do not have either data for GDP or data for years of schooling.

Table 4 Replication of Hanushek and Woessmann's regression results with test scores

Dependent variable: average annual growth rate in GDP per capita, 1960-2000			
	HW[a]	HWTEST[b]	TEST19902000[c]
GDP per capita	-0.302 ***	-0.290 ***	-0.310 ***
		(0.054)	(0.053)
Years of schooling	0.026	0.069	0.098
		(0.080)	(0.077)
Test scores (mean)	1.980 ***	1.662 ***	1.469 ***
		(0.220)	(0.188)
Constant	-4.737	-3.636	-2.738
		(0.849)	(0.709)
N	50	40[d]	40
R^2 (adj.)	0.728	0.6848	0.698

Note: Standard errors in parentheses Source: Author's compilation

a Results from Hanushek and Woessmann (2008)

b Standardized test scores from Hanushek and Woessmann (2008)

c Standardized test scores from 1990-2000 computed by the author

d No test scores data is available for China, India, and Zimbabwe alongisde the other seven missing countries (See Table 3 Note b)

Table 5 Replication of Hanushek and Woessmann's regression results with PWT 7.1

Dependent variable: average annual growth rate in GDP per capita				
	HW[a]	HWTEST[b]	TEST[c]	TEST2010[d]
Period	1960-2000	1960-2000	1960-2000	1960-2010
GDP per capita	-0.302 ***	-0.449 ***	-0.466 ***	-0.212 ***
		(0.104)	(0.103)	(0.040)
Years of schooling	0.026	0.082	0.125	0.068
		(0.202)	(0.197)	(0.077)
Test scores (mean)	1.980 ***	4.036 ***	3.562 ***	1.309 ***
		(0.581)	(0.503)	(0.205)
Constant	-4.737	-10.221	-8.022	-2.364
		(2.263)	(1.920)	(0.801)
N	50	40	40	40
R^2 (adj.)	0.728	0.5943	0.6036	0.6031

Note: Standard errors in parentheses Source: Author's compilation

a Results from Hanushek and Woessmann (2008)

b Standardized test scores from Hanushek and Woessmann (2008)

c Standardized test scores from 1990-2000 computed by the author

d Standardized test scores from 1990-2010 computed by the author

causes a change in the regression results. Furthermore, since the analysis strictly follows Hanushek and Woessmann's sample countries, it is worth conducting a robustness check with alternative compositions of the sample countries as well.

The following sections are devoted to test the robustness of Hanushek and Woessmann's result based on two different criteria. Firstly, by controlling for the composition of the countries in the sample, a robustness check is conducted to examine whether their regression results would change due to alternative time periods. Secondly, given the same time period, the sample size is altered to examine whether the regression result is robust to a change in the composition of sample size.

4.2 Sensitivity analysis with different time period

This section focuses on the robustness check of the regression model with different time period specifications. To perform the analysis, the sample size is controlled. There are five time periods and five slots of sample size. The slots of sample size are different in terms of the composition of sample countries. First, analysis strictly follows Hanushek and Woessmann's sample size, while more countries are added into the different slots of sample. Generally, the criterion to divide sample countries into different slots is based on the availability of the data for initial GDP per capita. For example, the data for initial GDP per capita in 1960 is available for 53 countries, but in 1970 the data is available for 62 countries.

Table 6 Altering time period with Hanushek and Woessmann's sample

Dependent variable: average annual growth rate in GDP per capita					
Period	1960-2010	1970-2010	1980-2010	1990-2010	2000-2010
GDP per capita	-0.562 ***	-0.178 ***	-0.124 ***	-0.110 ***	-0.095 ***
	(0.073)	(0.023)	(0.023)	(0.018)	(0.022)
Years of schooling	0.166	0.080	0.053	0.102	0.038
	(0.150)	(0.062)	(0.066)	(0.064)	(0.105)
Test scores (mean)	3.333 ***	1.367 ***	1.300 ***	0.877 ***	0.507 *
	(0.340)	(0.150)	(0.196)	(0.203)	(0.285)
Constant	-5.452	-2.672	-2.694	-0.913	1.182
	(1.414)	(0.615)	(0.788)	(0.834)	(1.231)
N	46a	47	47	47	47
R^2 (adj.)	0.7512	0.7129	0.5240	0.4522	0.3967

Note: Standard errors in parentheses Source: Author's compilation

a GDP per capita data is not available for Tunisia

Given Hanushek and Woessmann's sample, results are consistent in terms of statistical quality (Table 6); however, the magnitude of the rate of convergence and the effect of cognitive skills on economic growth declines when the period of analysis becomes shorter. This is also the case for R^2. Controlling for 53 sample countries, the results in Table 7 illustrates is consistent with Hanushek and Woessmann's result, except for column 5 in which test scores loses its significance. Similar results can be observed in Table 8 and 9, in which the magnitude of the convergence rate and test score as well as R^2 decrease from one period specification to another. By expanding the sample size from 53 countries to 62 countries and to 73 countries, the respective regression results remain consistent. The test scores in period 2000-2010 is still insignificant and the R^2 becomes lower than the analysis in Table 5. In addition, the test scores in period 1990-2010 turns insignificant (Table 9).

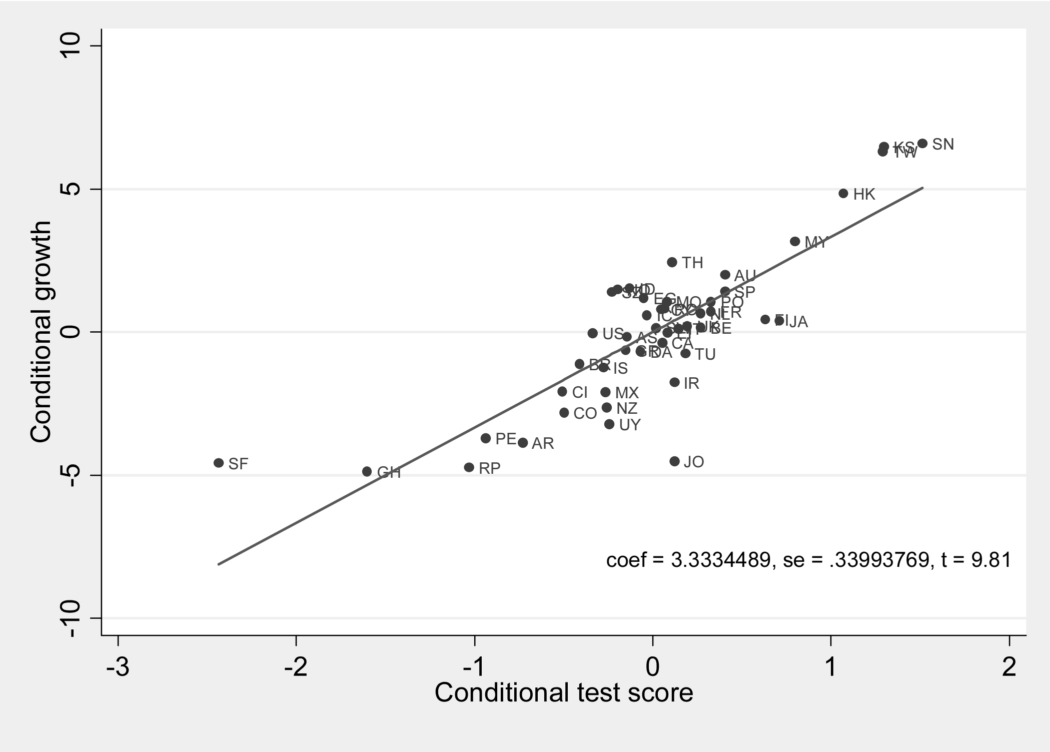

Fig. 1 Added-Variable Plot of Growth and Test Scores with 47-countries sample

Note: a Added-variable plot of a regression of the average annual rate of growth (in percent) of real GDP per capita in 1960-2010 on the initial level of real GDP per capita in 1960, average test scores on international student achievement tests, and average years of schooling in 1960.
b This figure corresponds to the result of Table 6 Column 1.
c The country abbreviation is based on the U.S. General Services Administration, 2012. "List of Countries by Two Letter Alpha Codes Only." http://www.gsa.gov/portal/content/101553
Source: Author's compilation

According to Table 7 and Table 8, it is possible to argue that given the same sample size, a change in time period specification would result in a change in the statistical quality of the results. The evidence, however, is ambiguous. One might argue that owing to a short period of 2000-2010 in column 5 (Table 7, Table 8 and Table 9), the analysis might not be relevant in the context of cross-country growth regression. In Table 9, the sample sizes are not vigorously controlled; therefore, the loss of statistical significance of test scores in both periods, 1990-2010 and 2000-2010, may come from the expansion of the sample size (see section 4.3).

Table 7 Altering time period with extended sample (53 countries)

Dependent variable: average annual growth rate in GDP per capita					
Period	1960-2010	1970-2010	1980-2010	1990-2010	2000-2010
GDP per capita	-0.526 ***	-0.155 ***	-0.096 ***	-0.078 ***	-0.058 ***
	(0.096)	(0.029)	(0.025)	(0.020)	(0.021)
Years of schooling	0.238	0.075	0.034	0.089	0.008
	(0.199)	(0.078)	(0.074)	(0.078)	(0.122)
Test scores (mean)	2.882 ***	1.181 ***	1.078 ***	0.561 **	0.099
	(0.467)	(0.191)	(0.218)	(0.240)	(0.317)
Constant	-3.796	-1.890	-1.841	0.233	2.698
	(1.893)	(0.768)	(0.861)	(0.973)	(1.350)
N	53	53	53	53	53
R^2 (adj.)	0.5215	0.5026	0.3368	0.2132	0.2162

Note: Standard errors in parentheses Source: Author's compilation

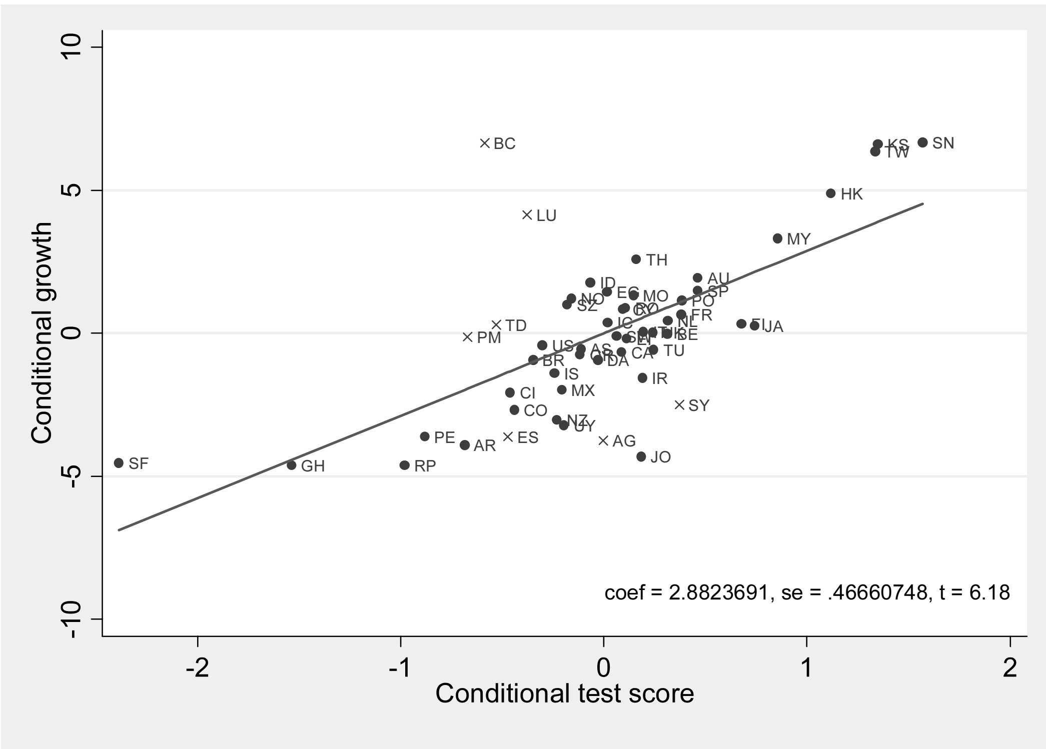

Fig. 2 Added-Variable Plot of Growth and Test Scores with 53-countries sample

Note: a Added-variable plot of a regression of the average annual rate of growth (in percent) of real GDP per capita in 1960-2010 on the initial level of real GDP per capita in 1960, average test scores on international student achievement tests, and average years of schooling in 1960.

b This figure corresponds to the result of Table 7 Column 1.

c The x mark in the diagram indicates the additional countries to Hanushek's sample.

Source: Author's compilation

Table 8 Altering time period with extended sample (62 countries)

Dependent variable: average annual growth rate in GDP per capita					
Period	1960-2010	1970-2010	1980-2010	1990-2010	2000-2010
GDP per capita	-0.526 ***	-0.150 ***	-0.102 ***	-0.064 ***	-0.073 ***
	(0.096)	(0.025)	(0.023)	(0.018)	(0.024)
Years of schooling	0.238	0.055	0.057	0.053	0.009
	(0.199)	(0.069)	(0.073)	(0.074)	(0.134)
Test scores (mean)	2.882 ***	1.089 ***	0.939 ***	0.420 *	0.351
	(0.467)	(0.206)	(0.243)	(0.243)	(0.382)
Constant	-3.796	-1.367	-1.240	0.938	1.989
	(1.893)	(0.817)	(0.943)	(0.958)	(1.590)
N	53	62	62	62	62
R^2 (adj.)	0.5215	0.4550	0.2766	0.1473	0.1626

Note: Standard errors in parentheses Source: Author's compilation

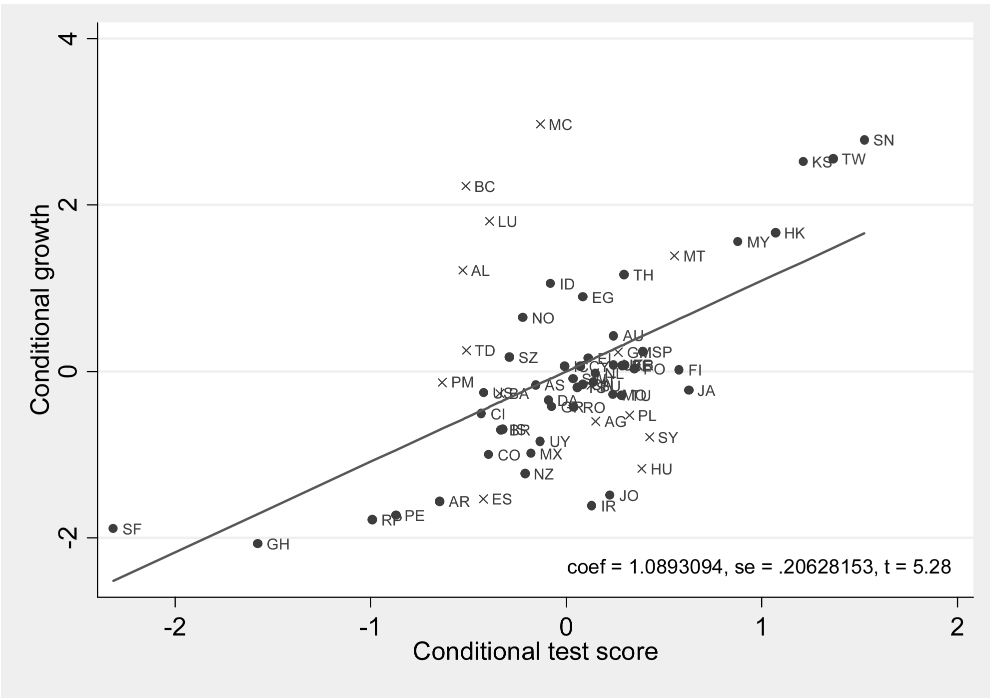

Fig. 3 Added-variable plot of growth and test scores with 62-countries sample (1970)

Note: a Added-variable plot of a regression of the average annual rate of growth (in percent) of real GDP per capita in 1970-2010 on the initial level of real GDP per capita in 1970, average test scores on international student achievement tests, and average years of schooling in 1970.

b This figure corresponds to the result of Table 8 Column 2.

c The x mark in the diagram indicates the additional countries to Hanushek's sample.

Source: Author's compilation

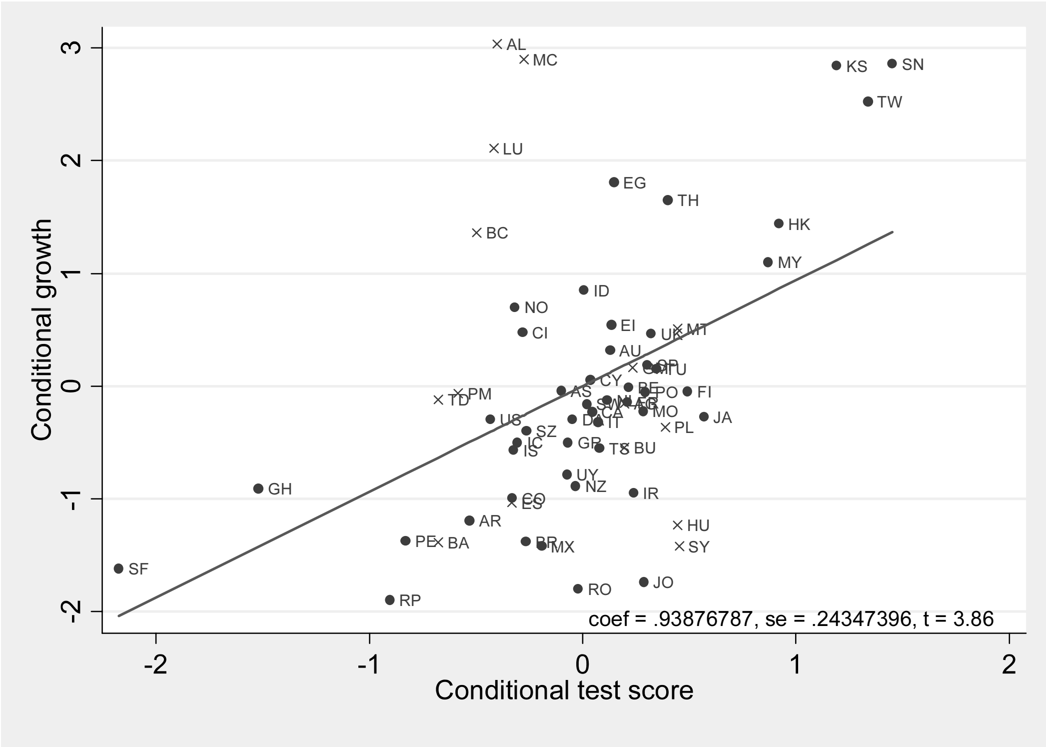

Fig. 4 Added-variable plot of growth and test scores with 62-countries sample(1980)

Note: a Added-variable plot of a regression of the average annual rate of growth (in percent) of real GDP per capita in 1980-2010 on the initial level of real GDP per capita in 1980, average test scores on international student achievement tests, and average years of schooling in 1980.

b This figure corresponds to the result of Table 8 Column 3.

c The x mark in the diagram indicates the additional countries to Hanushek's sample.

Source: Author's compilation

Table 9 Altering time period with extended sample (73 countries)

Dependent variable: average annual growth rate in GDP per capita					
Period	1960-2010	1970-2010	1980-2010	1990-2010	2000-2010
GDP per capita	-0.526 ***	-0.150 ***	-0.102 ***	-0.024 *	-0.039 **
	(0.096)	(0.025)	(0.023)	(0.014)	(0.017)
Years of schooling	0.238	0.055	0.057	-0.023	0.013
	(0.199)	(0.069)	(0.073)	(0.077)	(0.130)
Test scores (mean)	2.882 ***	1.089 ***	0.939 ***	0.026	-0.137
	(0.467)	(0.206)	(0.243)	(0.254)	(0.378)
Constant	-3.796	-1.367	-1.240	2.641	3.747
	(1.893)	(0.817)	(0.943)	(0.937)	(1.391)
N	53	62	62	73	73
R^2 (adj.)	0.5215	0.4550	0.2766	0.0205	0.0636

Note: Standard errors in parentheses　　Source: Author's compilation

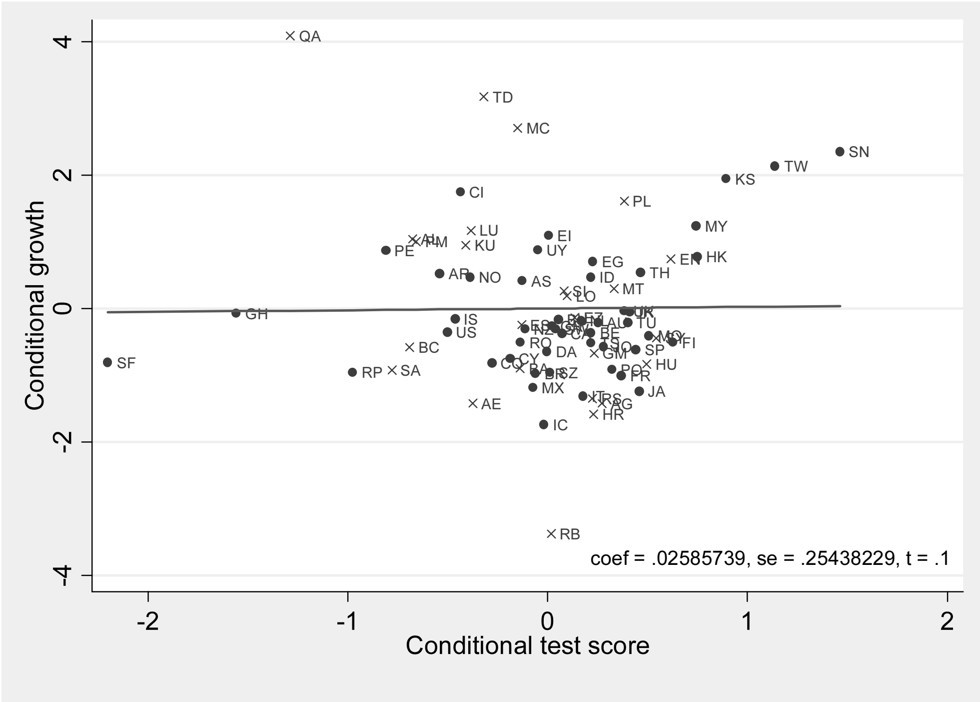

Fig. 5 Added-variable plot of growth and test scores with 73-countries sample (1990)

Note: a Added-variable plot of a regression of the average annual rate of growth (in percent) of real GDP per capita in 1990-2010 on the initial level of real GDP per capita in 1990, average test scores on international student achievement tests, and average years of schooling in 1990.
b This figure corresponds to the result of Table 9 Column 4.
c The x mark in the diagram indicates the additional countries to Hanushek's sample.
Source: Author's compilation

4.3 Sensitivity analysis with different sample composition

In contrast to section 4.2 that focuses on the robustness check of the regression model with different time period specifications, this section focuses on the robustness check of the regression model with a different sample size. To conduct the analysis, the period of analysis is controlled. In period 1960-2010 (Table 10), results are fairly consistent; however, the magnitude of test scores and R^2 are somewhat different. In period 1960-2010 (column 1), test scores that are larger by one standard deviation are associated with an average annual growth rate in GDP per capita that is 3.3 percentage points higher over the entire fifty-year period. On the contrary, the effect of test scores from period 1970-2010 (column 2) is lesser by a considerably high 0.5 percentage points. By introducing seven more countries into the sample, a large reduction in both the magnitude of test scores and R^2 can be observed. As a result, there may be a self-selection bias with Hanushek and Woessmann's sample that can lead to an overestimation of the effect of test scores on economic growth.

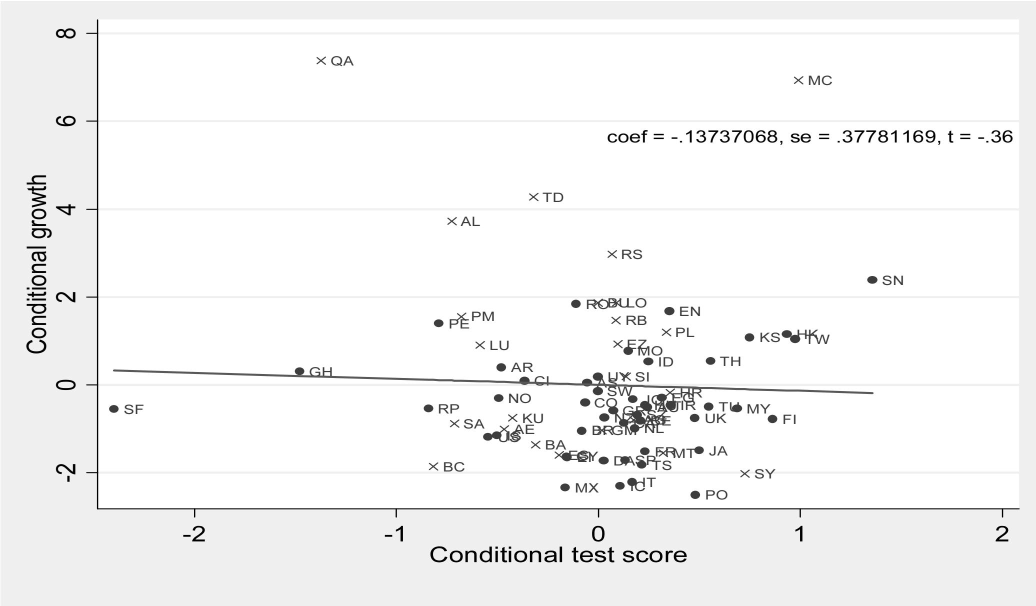

Fig. 6 Added-variable plot of growth and test scores with 73-countries sample (2000)

Note: a Added-variable plot of a regression of the average annual rate of growth (in percent) of real GDP per capita in 2000-2010 on the initial level of real GDP per capita in 2000, average test scores on international student achievement tests, and average years of schooling in 2000.

b This figure corresponds to the result of Table 9 Column 5.

c The x mark in the diagram indicates the additional countries to Hanushek's sample.

Source: Author's compilation

In periods 1970-2010, 1980-2010, and 1990-2010 (Table 11, Table 12, and Table 13), the results are consistent. With Hanushek and Woessmann's sample, the model can account for around 70 percent of the variation of the growth rate, whereas after introducing a new set of countries into the analysis R^2 becomes lower. Somehow, introducing a new set of countries dilutes the explanation power of the model. In Table 14, adding more countries in the sample results in a loss of statistical significance of test scores in all analyses (column 2, 3 and 4). R^2 in all columns, except for the analysis with Hanushek and Woessmann's sample (column 1), is fairly low. Moreover, R^2 declines progressively with the introduction of new countries. It seems that the regression with Hanushek and Woessmann's choice of sample is consistent with their original result while analyses with other compositions of the countries in the sample size can possibly result in inconsistent results. So far, the convergence rate is strongly statistically significant across all sensitivity analyses, while test scores become insignificant in only few robustness checks. Thus, it can be argued that Hanushek and Woessmann's result has a tendency to be sensitive to the composition of sample size.

Table 10 Altering composition of the sample with 1960-2010 time period

Dependent variable: average annual growth rate in GDP per capita		
GDP per capita	-0.562***	-0.526***
	(0.073)	(0.096)
Years of schooling	0.166	0.238
	(0.150)	(0.199)
Test scores (mean)	3.333***	2.882***
	(0.340)	(0.467)
Constant	-5.452	-3.796
	(1.414)	(1.893)
N	46	53
R^2 (adj.)	0.7512	0.5215

Note: Standard errors in parentheses Source: Author's compilation

Table 11 Altering composition of the sample with 1970-2010 time period

Dependent variable: average annual growth rate in GDP per capita			
GDP per capita	-0.178***	-0.155***	-0.150***
	(0.023)	(0.029)	(0.025)
Years of schooling	0.080	0.075	0.055
	(0.062)	(0.078)	(0.069)
Test scores (mean)	1.367***	1.18***	1.089***
	(0.150)	(0.191)	(0.206)
Constant	-2.672	-1.890	-1.367
	(0.615)	(0.768)	(0.817)
N	47	53	62
R^2 (adj.)	0.7129	0.5026	0.4550

Note: Standard errors in parentheses Source: Author's compilation

Table 12 Altering composition of the sample with 1980-2010 time period

Dependent variable: average annual growth rate in GDP per capita			
GDP per capita	-0.124***	-0.096***	-0.102***
	(0.023)	(0.025)	(0.023)
Years of schooling	0.053	0.034	0.057
	(0.066)	(0.074)	(0.073)
Test scores (mean)	1.300***	1.078***	0.939***
	(0.196)	(0.218)	(0.243)
Constant	-2.694	-1.841	-1.240
	(0.788)	(0.861)	(0.943)
N	47	53	62
R^2 (adj.)	0.5240	0.3368	0.2766

Note: Standard errors in parentheses Source: Author's compilation

Table 13 Altering composition of the sample with 1990-2010 time period

Dependent variable: average annual growth rate in GDP per capita				
GDP per capita	-0.110***	-0.078***	-0.064***	-0.024*
	(0.018)	(0.020)	(0.018)	(0.014)
Years of schooling	0.102	0.089	0.053	-0.023
	(0.064)	(0.078)	(0.074)	(0.077)
Test scores (mean)	0.877***	0.561**	0.420*	0.026
	(0.203)	(0.240)	(0.243)	(0.254)
Constant	-0.913	0.233	0.938	2.641
	(0.834)	(0.973)	(0.958)	(0.937)
N	47	53	62	73
R^2 (adj.)	0.4522	0.2132	0.1473	0.0205

Note: Standard errors in parentheses Source: Author's compilation

Table 14 Altering composition of the sample with 2000-2010 time period

Dependent variable: average annual growth rate in GDP per capita				
GDP per capita	-0.095***	-0.058***	-0.073***	-0.039**
	(0.022)	(0.021)	(0.024)	(0.017)
Years of schooling	0.038	0.008	0.009	0.013
	(0.105)	(0.122)	(0.134)	(0.130)
Test scores (mean)	0.507*	0.099	0.351	-0.137
	(0.285)	(0.317)	(0.382)	(0.378)
Constant	1.182	2.698	1.989	3.747
	(1.231)	(1.350)	(1.590)	(1.391)
N	47	53	62	73
R^2 (adj.)	0.3967	0.2162	0.1626	0.0636

Note: Standard errors in parentheses Source: Author's compilation

4.4 Implications and discussions

Results of the first robustness check with a change in data set of GDP per capita from PWT 6.1 to PWT 7.1 complies with that of Hanoushek, et al. (2004). Using data that has been adjusted can possibly influence the real effect of test scores on economic growth due to a change in the quality of data (Hanoushek, et al., 2004 and Deaton (2011)). As Deaton (2011) puts it, "better data on more outcomes and more countries is changing our view of development". Results in this paper suggest that a new pattern of the causal relationship between cognitive skills and economic growth might be discovered with a better data set in the future. Although, the real effect of test scores may change, the statistical quality should not vary considerably if the test scores truly belong to the main driving forces of country growth. The analysis, however, does not control for the sample size and time period of analysis. Variations in these factors may also have an impact on sensitivity analysis.

For the second robustness check, sensitivity to different time periods was examined and test scores turned insignificant in some analyses. This may occur for various reasons. Firstly, it might suggest that in previous years, i.e. 1960-1990, cognitive skills might have been a main driver of growth. However, due to economic transition, skills required in the labor market or the key to economic growth have changed. In addition to cognitive skills, non-cognitive skills might also play an important role in economic development now.

There is also a possibility of a lagged effect of test score. Hanushek and Woess mann's analysis implicitly assumes that the depreciation of cognitive skills and lag effect of education do not appear in the model since student achievement scores were used as a proxy of human capital, rather than that of worker or labor force. Obviously, students are the future labor force, but their cognitive skills might appreciate or depreciate by that time. In fact, cognitive skills or human capital can appreciate and depreciate over time, depending on the nature of tasks and work. For example, farm-related work requires less literacy competency than that of secretarial work; there is a higher chance for farmers to lose literacy or cognitive skills if their work requires only basic reading and less thinking.

Furthermore, test scores in a current period might not be able to predict the economic growth in the same period due to the lag effect of student scores—students do not enter the labor market right after the testing date. Thus, there is a time-inconsistency problem in Hanushek and Woessmann's regression model, in which the average student achievement scores in period 1960-2010 are calculated and used to estimate the economic growth in the same period. Ignoring the appreciation or depreciation and lag effects might lead to an overestimation of the effect of test scores on growth. Appleton, Atherton, and Bleaney (2008) found that after taking lag effects into account, the effect of test scores on long-term growth is statistically significant, but remarkably smaller than that reported by Hanushek and Kimko (2000) and Hanushek and Woessmann (2008). Notwithstanding, the Appleton, Atherton, and Bleaney (2008) model is still unable to capture the appreciation or depreciation of human capital over time—cognitive skills, in this case; the problem of stocks and flows measurement of test scores still prevails.

In terms of a sensitivity analysis based on a change in countries composition of the sample, alternating the composition of sample size can lead to changes in the results. This may suggest that after introducing new countries, test scores become a minor factor explaining the growth for a larger sample size where more variations among countries can be observed. Thus, Hanushek and Woessmann's result might be overestimated. Furthermore, there might be a self-selection bias in Hanushek and Woessmann's sample. The regression results might be driven by a certain group of countries who are willing to participate in international student assessment tests and thus share similar characteristics.

Adding a new set of countries turns test scores insignificant (Table 13 and Table 14). The added countries include Albania, Bahrain, Bulgaria, Croatia, Czech Republic, Dubai (UAE), Estonia, Germany, Hungary, Kuwait, Macao-China, Malta, Poland, Qatar, Russia, Saudi Arabia, Serbia, Slovak Republic and Slovenia. According to World Bank's (2012) country classification, one immediate observation regarding the added countries is that most are high income economies in the category of upper-middle income economies. In addition, in terms of geopolitical area, these countries can be divided into two main regions—Europe and Central Asia, as well as Middle East and North Africa.

A common characteristic of the countries from Europe and Central Asia is that they are newly-born countries in the sense that these countries separated from previous unions (e.g. countries from the Soviet Union and former Yugoslavia) or two or more countries becoming a union (e.g. East and West Germany). This phenomenon of emerging countries occurred around the same period, 1991-1993, which may have implications on a country's growth pattern. As for educational indicators, countries in this group have a high school attainment rate, ranging from 9 years to 12 years. However, there is a wide variation in test scores among countries in this group ranging from 340 to 480 within the same region.

Countries from Middle East and North Africa, so-called the Arab League, are petroleum-rich countries. Exporting petroleum and natural gas are a main source of income. However, due to limited reserves, Arab countries have started diversifying their economies over the past decade. In terms of education, years of schooling are fairly low in some countries—the school attainment rate for the adult population over age 25 ranges from 4.5 years to 8 years. In addition, test scores are relatively lower than the first region. These countries, however, are classified as high income economies. Thus, the relationship between test scores and economic growth might not be observed in this group. Adding these countries into the main regression may in turn may dilute a causal relationship between test scores and economic growth.

5. Conclusion

Thus far, Section 4 has sought to provide a logical flow of sensitivity analyses. Strictly following Hanushek and Woesmann's sample, the results from the simple specification (with only initial GDP per capita and school attainment included) is consistent with that of Hanushek and Woessmann—both the coefficient of convergence and school attainment are statistically significant. However, after adopting a new data set for GDP per capita, the association between years of schooling and growth turns insignificant. A robustness check was conducted to examine whether a difference in regression results can be observed with changes in time periods or composition of the sample size.

In looking at changes in regression results with changes in time periods, the result is ambiguous. Analyses with short periods, 1990-2010 and 2000-2010, might not be relevant in the context of cross-country growth regression. Sample sizes were also not vigorously controlled. Therefore, the loss of statistical significance of the test scores in both periods may be due to the expansion of sample size. In looking at changes in sample composition, introducing a few more countries into the sample led to a large reduction in both the magnitude of test scores and the R^2 value. This may imply a self-selection problem with Hanushek and Woessmann's sample, which can lead to an overestimation of the effect of test scores on economic growth.

In sum, this paper has thus sought to argue that Hanushek and Woessmann's result is reasonably robust to most sensitivity analyses. However, changing the compositions of sample size and data set may affect the results. The convergence rate remained strongly statistically significant across all sensitivity analyses, but test scores became statistically insignificant in some sensitivity analyses.

While the further introduction of sample countries would require a systematic analysis of the added countries, it is beyond the scope of this research and remains an empirical question. It is encouraged for future research to systematically analyze the common characteristics of Hanushek and Woessmann's sample and also of the additional countries added. Moreover, an interpretation of convergence rate should be further scrutinized, especially on whether the introduction of a new set of countries affects the magnitude or the effect of the convergence rate, compared to the traditional effect of the rate.

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